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Status of geothermal energy amongst Turkey's energy sources

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Abstract

This article presents a comparison between geothermal energy and other energy sources in Turkey. Turkey's primary energy consumption is about 64 Mtoe in 2003, mostly provided by fossil fuels (74.7%). Renewables collectively provide 25.3% of the primary energy, in the form of hydro (14.6%), combustible renewable and waste (9%), geothermal (1.2%), and the other renewables (0.5%). Although Turkey has a great geothermal potential (Turkey is the seventh richest country in the world in geothermal energy potential), it uses only about 4% of this potential efficiently. Present applications have shown that geothermal energy is clean and much cheaper compared to the other fossil fuels and other renewable energy sources for Turkey. Therefore, it is a promising alternative and development studies and investments in this sector should be supported.

Keywords: Geothermal energy; Electricity; Direct use; Renewables; Energy prices

Contents

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1. Introduction

Despite the limitations of the Earth's conventional energy resources, the demand for energy is continuously rising as a result of increasing population and industrialization. The utilization of fossil energy resources is presently causing increasingly disastrous effects on the global environment. In this regard, there is an urgent need to deploy sustainable and environmentally clean energy sources. An important contribution could be made by rapidly expanding the use of renewable energy sources, such as geothermal energy [1].

Among the problems related to technological developments lie the insufficiency of energy resources and the environmental pollution provoked by this shortage. The conflict between the energy and pollution—two factors which are significant for both today and the future of humanity, the rise in environmental pollution being parallel to the rise in energy generation and consumption—requires that these two factors be handled together in order to solve the problems. Under these circumstances, energy resources that are sustainable and sensitive to the environment should be used. Thus, policies that reduce the consumption of fossil fuels and encourage the use of such sustainable energy resources as geothermal, hydropower, solar, wind, biomass, and wave should be researched. All the renewable technologies have a significant positive effect on global warming. Geothermal energy, one of the most promising among renewable energy sources, has proven to be reliable, clean, and safe, and therefore, its use for power production, and heating and cooling is increasing. Geothermal energy is a power source that produces electricity with minimal environmental impact [2,3].

Geothermal energy is the energy contained as heat (the thermal energy) in the Earth's interior. The origin of this heat is linked with the internal structure of our planet and the physical processes occurring there [4]. Geothermal energy is to some extent a renewable energy source since a geothermal resource usually has a projected life of 30–50 yr. The life of a resource may be prolonged by a reinjection process, which may compensate for at least part of the fluid extracted by production [1].

Although almost all energy resources exist in Turkey, the resources except for lignite and hydropower are not used to meet the needs of the country, and thus, more than half of the energy supply is imported [5]. In summary, Turkey needs alternative energy resources in order to meet the increasing demand and, thus, improve the productivity of natural resources in view of technical, economical, social, political, and environmental effects [6]. Geothermal energy, hydropower, solar energy, wind power, and biomass energy are the major resources to provide Turkey with most of its renewable energy in the future. Provided that geothermal energy, which has a considerable potential in Turkey, is used in electricity generation, besides heating and greenhouses, the energy problem in Turkey will be remarkably solved. Recent developments have proved that the most important field of usage of geothermal energy in the future will be electricity generation [5].

Turkey has a place among the first seven countries (the existence of more than 600 hot springs) in terms of the abundance of geothermal resources around the world. The data

accumulated since 1962 show that the estimated geothermal power and direct use potential are about 4500 and 31,500 MW, respectively. However, only 2–3% of this potential has so far been utilized [1].

This article starts with a description of recent energy forecasts for the Turkey in the new century. The present use of energy sources is summarized. A comparison is made between geothermal energy and some other energies economically and environmentally.

2. Turkey's energy forecasts

Energy issues are directly related to the development of a country and the living standards of its people. Turkey is currently in a rapid industrialization process with a young and dynamic population of over 70 million. Due to relatively high growth rate of the population, increasing consumer-oriented attitudes and as a result of rising levels of affluence, the primary energy demand is rising rapidly at an average annual rate of 6.8%. Turkey is currently projected to remain a net importer of energy, with more than 60% of its needs to be imported in 2020 [7].

While the energy demand of Turkey is estimated to be doubled between the years 2005 and 2020, it is forecasted to be about five fold between the years 2005 and 2030. This rapid increase in demand is due to the high economic development rate of Turkey. The amount of the primary energy sources and primary energy consumption of Turkey between 2005 and 2025 is given in Table 1. Primary energy consumption is expected to increase from 119 million tonnes of oil equivalents (Mtoe) in 2005 to 229 Mtoe by 2015 and to 535 Mtoe by 2025. In Turkey, electricity is produced by thermal power plants consuming coal, lignite, natural gas, fuel oil, and geothermal energy and hydropower plants. According to 2004 data, Turkey produces 24 Mtoe a year from its own primary sources and consumes 64 Mtoe a year of primary energy. It is expected that by the year 2020, primary energy production will be 66 Mtoe, while primary energy consumption will be 310 Mtoe.

As can be seen in Table 1, it is expected that energy resource had the most important rate in 2025 will be coal, with approximately 56%. The renewable energy source which has the

Table 1
Primary energy consumption of Turkey between 2005 and 2025 (ktoe)

Energy source	2005	2010	2015	2020	2025
Coal (h. coal + lignite)	30,474	50,311	83,258	129,106	296,997
Oil and natural gas	73,256	92,637	112,993	136,365	179,765
Wood and waste	6760	6446	6029	5681	5393
Hydropower	5845	7520	8873	9454	10,445
Geothermal	1380	3760	4860	4860	5400
Nuclear	0	3657	9143	18,286	29,200
Solar	459	907	1508	2294	3248
Central heating	495	884	1336	2018	2748
Wind	250	620	980	1440	2134
Total	118,919	166,742	228,980	309,504	53,5330

Source: Ref. [8].
ktoe: kilo tonnes of oil equivalent.

Table 2
Projected electricity capacities of Turkey

	Capacity				Annual production			
	Year of 2010		Year of 2020		Year of 2010		Year of 2020	
	MW_e	%	MW_e	%	Mtoe	%	Mtoe	%
Geothermal	258	0.4	350	0.3	1.98	5.4	4.81	7.3
Hydro	25,442	39.3	30,902	28.3	4.90	13.4	9.42	14.3
Fossil fuel	37,024	57.1	46,661	42.7	24.48	66.7	37.68	57.4
Nuclear energy	2082	3.2	10,410	9.5	—	—	8.23	12.5
Total	64,806	100.0	109,218	100.0	36.69	100.0	65.65	100.0

Source: Refs. [9,10].

largest amount in 2025 will be hydropower energy (1.95%). Geothermal energy will have 1.01% of Turkey's primary energy consumption.

Turkey's energy use has increased steadily with economic and population growth. The present status and projections of the installed capacity and annual production of electricity in Turkey are given in Table 2. The table also shows the situation of geothermal power production as compared to the other sources of electricity projections for 2010 and 2020. In the coming decades, it is estimated that geothermal energy production by 2010 and 2020 will be 1.98 and 4.81 Mtoe, respectively.

As seen in Table 3, Turkey is not rich in fossil fuel resources, except for lignite so as to meet its own energy demand in a self-sufficient way [11]. Turkey is poor in fossil fuel resources but rich in renewables such as geothermal, solar, wind, biomass, and hydropower. The studies on renewable energy sources in Turkey were started in 1960s but could not exhibit a significant progress by the present time except hydropower, as it has happened in several well-developing countries. Geothermal resources of the country are wide spread but the favourable reserve for heating and generating electricity is limited and even this limited reserve has not yet been used [9].

Based on an evaluation of its fossil fuel reserves, which total 2.454 Mtoe, it is expected that Turkey will be forced to import energy in increasing proportions. For this reason, Turkey attaches considerable importance to renewable energies [8]. Turkey has the potential for 124 TWh/yr of hydropower, 16.9 Mtoe/yr of biomass energy, 1.8 Mtoe/yr of geothermal power, 35.2 Mtoe/yr of solar energy, and 50 TWh/yr of wind power in usable quantities.

3. Turkey's energy sources

Although Turkey has almost all kinds of energy resources, it is an energy importing country; more than half of the energy requirement has been supplied by imports (Table 4). Therefore, it seems that if the country wants to supply its demand by domestic resources (such as lignite, hard coal, oil, and natural gas), the transition to renewable energy resources must be realized in a reasonable time period [12]. Oil has the biggest share in total primary energy consumption. The high level of dependence on imported petroleum and natural gas is the dominant factor in Turkey's pattern of energy consumption [7].

Table 3
Primary energy source reserves of Turkey

Energy source	Proven	Probable	Possible	Total
Fossil fuels				
Hard coal (Mt)	428	456	245	1126
Lignite (Mt)	7339	626	110	8075
Asphaltite (Mt)	45	29	8	82
Bituminous shale (Mt)	555	1086	0	1641
Crude oil (Mt)	41.8			41.8
Natural gas (billion m^3)	8.7			8.7
Nuclear sources (t)				
Natural uranium	9129			9129
Thorium	380,000			380,000
Renewables				
Hydro				
TWh/yr	124			124
MW/yr	34,729			34,729
Geothermal (Mtoe/yr)	1.8			
Electricity (MW/yr)	200		4300	4500
Thermal (MW/yr)	2600		28,900	31,500
Wind (TWh/yr)	50	120	230	400
Biomass (Mtoe/yr)	16.9			32
NPP (DW Mt/yr)				
Forest NPP				86–412
Terrestrial NPP				191–1660
Terrestrial NPP + aquatic NPP				202–1730
Solar energy (Mtoe/yr)	35.2		52.8	88
Electricity	8.8			
Thermal	26.4			

Source: Ref. [11].
NPP, net primary productivity.

The share of petroleum in consumption of commercial primary energy decreased by 2.2% and the share of natural gas in consumption of commercial primary energy rose by 51.2% from 2002 to 2003.

Turkey's primary energy sources include hydropower, geothermal, lignite, hard coal, oil, natural gas, wood, animal and plant wastes, solar and wind energy. In 2003, primary energy production and consumption has reached 23.81 and 63.83 Mtoe, respectively. Table 4 shows the Turkey's primary energy consumption and production in 2002 and 2003. Fossil fuels provided about 75% of the total energy consumption of the year 2003, with oil (41%) in first place, followed by coal (21%), and natural gas (12%). Turkey has not utilized nuclear energy as yet. The renewables collectively provided 25% of the primary energy, mostly in the form of hydropower (about 15%), combustible renewables and wastes (9%), geothermal (1.2%), and much less by other renewable energy resources (approximately 0.5%).

If we take electricity production only, the role of hydropower becomes much more significantly. The Turkey's electricity production was about 150,698 GWh in 2004, compared to 2815 GWh in 1960 (Table 5). Most of the electricity was produced by natural

Table 4
Turkey's primary energy production and consumption

Energy source	Consumption of year 2002		Production of year 2002		Consumption of year 2003		Production of year 2003		Increase (2002–2003) in consumption (%)
	Mtoe	%	Mtoe	%	Mtoe	%	Mtoe	%	
Fossil fuels									
Oil	26.94	47.7	2.39	9.8	26.36	41.3	2.49	10.5	−2.2
Natural gas	5.22	9.2	0.31	1.3	7.89	12.4	0.51	2.1	+51.2
Coal	8.61	15.2	11.64	47.6	13.39	21.0	10.81	45.4	+55.5
Renewables									
Hydro	8.73	15.4	2.90	11.9	9.32	14.6	3.04	12.8	
Geothermal	0.73	1.3	0.82	3.4	0.78	1.2	0.86	3.6	+6.9
Solar/wind/other	0.32	0.6	0.32	1.3	0.35	0.5	0.36	1.5	+9.4
Combustible renewable and wastes	5.97	10.6	6.05	24.8	5.75	9.0	5.75	24.1	−3.7
Nuclear	—	—	—	—	—	—	—	—	
Total	56.52	100	24.43	100	63.83	100	23.81	100	+12.9

Source: Ref. [10].

Table 5
Turkey's production of electricity by source (GWh)

Energy source	Years							
	1960	1970	1980	1990	2000	2002	2003	2004
Fossil fuels	1773	5425	11,792	34,315	93,714	95,389	104,985	104,360
Hard coal	1008	1382	912	621	3819	4090	8663	11,996
Lignite	533	1442	5049	19,561	34,367	28,056	23,590	22,450
Natural gas	—	—	—	10,192	46,217	52,497	63,536	62,242
Nuclear	—	—	—	—	—	—	—	—
Renewables	1042	3199	11,484	23,228	31,208	34,010	35,596	46,339
Total production	2815	8623	23,275	57,543	124,922	129,400	140,581	150,698
Total consumption		7308	20,398	46,820	98,296	102,948	111,766	121,142

Source: Ref. [13].

gas (41%), followed by coal (23%), hydro (31%), and oil (5%) in 2004. Only 0.2% of the electricity was provided by the "new renewables" (combustible renewables and waste, geothermal, and wind) while 69% of electricity was produced by fossil fuels in 2004.

4. Geothermal energy

Although geothermal energy is categorized in international energy tables as one of the new renewables, it is not a new energy source at all. Before the 1960s, geothermal resources were used spontaneously in bathing and medical treatment in Turkey. Geothermal energy explorations in Turkey have been carried out by The General Directorate of Mineral Research and Exploitation (called MTA in Turkey).

The inventorial works and chemical analyses of the hot springs and mineral waters started in 1962. Since then, the first geothermal well was drilled in the Izmir-Balcova geothermal field in 1963. The same year, the Denizli-Kizildere geothermal field was discovered. The first space heating application by geothermal energy was in a hotel in Gonen-Balikesir in 1964 and the first geological, geochemical, and geophysical studies were carried out with support of the United Nations Development Program (UNDP) in the Denizli-Kizildere geothermal field in 1966. The investigations of geothermal energy in the country gained speed in the 1970s. A pilot power plant with a capacity of 0.5 MW_e was installed in the Denizli-Kizildere geothermal field in 1974. The utilization of geothermal energy could not become sufficiently widespread due to the scaling problems up to the early 1980s. Since then, the important developments have been recorded in geothermal energy utilization. The Aydin geothermal field was discovered in 1982. The first downhole heat exchanger system was installed in Izmir-Balcova in 1983 [14]. The Denizli-Kizildere geothermal power plant, which is at present the only operating geothermal power plant in Turkey, was put into operation by the Turkish Electricity Establishment (renamed as Turkish Electricity Generation and Transmission Corporation, TEAS) in 1984. The first greenhouse heating system of 0.45 ha by geothermal energy was begun in Denizli-Kizildere geothermal field in 1985. The first experimental study on a geothermal (ground-source) heat pump with a horizontal loop configuration at the university level was carried out in

the Mechanical Engineering Department, Middle East Technical University, Ankara in 1986, while that with a vertical loop configuration was performed in the Solar Energy Institute, Ege University, Izmir in 2000. Geothermal district heating applications started in 1987 in Turkey with heating of 600 residences in Balikesir-Gonen. After 1990, geothermal direct-use applications increased as steeply as 185% from 1990 to 1995. The first residential geothermal heat pump system (or ground-source heat pump system) was installed in a villa with a floor area of 276 m^2 in Istanbul in 1998. Recently, geothermal direct-use applications have reached up to 52,000 residences equivalence of geothermal heating, and engineering design of nearly 300,000 residences equivalence geothermal district heating has been completed [15,16].

Turkey has an important place among the richest countries (the first in Europe, seventh in the world) in geothermal potential. Around 1000 hot and mineralized natural self-flowing springs exist in Turkey. The geothermal resources in Turkey can be classified into three groups: low temperature fields (<70 °C), moderate temperature fields (70–150 °C), and high temperature fields (more than 170 °C). Although they exist all over the country, most of them lie in the Western, North-Western, and Middle Anatolia. The temperature limit is accepted to be 20 °C for balneological purposes. With this exception, there are 170 geothermal fields with a temperature over 35 °C in Turkey—Aydın-Germencik (232 °C), Denizli-Kızıldere (242 °C), Çanakkale-Tuzla (173 °C), and Aydın-Salavatlı (171 °C) fields—that are suitable for electricity generation. Depending on the use of new technologies, the Manisa-Salihli-Caferbeyli (155 °C), Kütahya-Simav (162 °C), Izmir-Seferihisar (153 °C), Dikili (130 °C), and Denizli-Gölemezli (under search) fields can be used in electricity generation and the others are suitable for direct use [17].

In 2005, geothermal energy use of Turkey amounted to about 119.7 GWh/yr of electricity and 6900.5 GWh/yr for direct use. Turkey is one of the countries with significant potential in geothermal energy. Data accumulated since 1962 show that there may be existed about 4500 MW of geothermal energy usable for electrical power generation in high enthalpy zones [18]. A recent estimate of the geothermal potential of Turkey gives the total potential resources for direct use in excess of 31,500 MW_t. These figures for the potential cover both known and unidentified resources. Proven, probable, and possible potential of Turkey are given in Table 6. The identified geothermal resources is estimated to be 200 MW_e for electricity generation (resource temperature in excess of 473 K) and in excess of 3293 MW_t heat for direct use (resource temperature lower than 473 K).

Table 6
Status of Turkey's geothermal energy in 2005

	Proven potential (MW)	Probable and possible potential (MW)		
Heating (<473 K)	3293 MW_t	31,500 MW_t		
Electricity (>473 K)	200 MW_e	4500 MW_e		
	Capacity (MW_t)	Use (TJ/yr)	Use (GWh/yr)	Capacity factor
Direct use	1495	24,839.9	6900.5	0.53
Electricity	20.4		119.73	

Source: Refs. [2,19,20].

Table 7
Capacity in geothermal utilization in Turkey

Geothermal utilization	Capacity
District heating	827 MW_t
Balneological utilization	402 MW_t
Total direct use	1229 MW_t
Carbon dioxide production	120,000 t/yr
Power production	*20 MW_e (Denizli-Kızıldere) (operating)
	*25 MW_e (Germencik) (under construction)
	*10 MW_e (Aydın Salavatlı) (under construction)

Source: Ref. [21].

Table 7 shows capacity in geothermal utilization in Turkey. Most of the development in the direct use has been in district heating, which now serves 103,000 residences (827 MW_t and 7712.7 TJ/yr), and in individual space heating (74 MW_t and 816.8 TJ/yr). A total of 800,000 m^2 of greenhouses are heated by geothermal fluids (192 MW_t and 3633 TJ/yr). Geothermal heated pools used for bathing and swimming account for a capacity of 402 MW_t and utilize 12677.4 TJ/yr. About 120,000 tonnes of liquid carbon dioxide and dry ice are produced annually at the Kizildere power plant. By the year 2010, Turkey aims at having 500 MW_e dedicated to electricity generation and 3500 MW_t for space heating. Heat pumps are not being used at present, because of the high cost of electricity [20].

It is clear that the present use of geothermal energy is a very small fraction of the identified geothermal potential. Four per cent of geothermal source potential of Turkey is only evaluated up to 2005. When Turkey uses all of the total geothermal potential it can meet 12.7% of the total energy need (heat + electricity) from geothermal energy. There is certainly space for an accelerated use of geothermal energy both for electricity generation and direct use in the near future.

5. Comparison of geothermal with other renewables

As summarized in Table 8, renewable energy supply is estimated to increase from 10 Mtoe in 2003 to 12 Mtoe by 2010 and 20 Mtoe by 2020. Electricity generation from renewables is expected to increase from 35.5 TWh in 2003 to 62 TWh by 2010 and 118 TWh by 2020. Use of renewables for heat production is estimated to drop from 6.9 Mtoe in 2003 to 6.6 Mtoe by 2010 but to grow to 9.3 Mtoe by 2020.

Turkey has substantial renewable energy resources. Renewables make the second-largest contribution to domestic energy production after coal. The installed capacity and the electricity production between from 1960 to 2004 for some new and renewable energy sources, namely hydropower, combustible renewable and waste, geothermal, and wind energy are given Table 9 where the data were compiled from statistical reports of Turkish Electricity Transmission Company (TEİAŞ). The total electricity production from renewables in 2004 was 46339 GWh. By far the largest contribution (99.4%) came from hydropower, but 0.2% came from combustible renewable and waste, 0.2% from geothermal, and 0.1% from wind. It has not been carried out the electricity production from other new renewables such as solar energy, wave and tidal energy, etc.

Table 8
Renewable energy projections in Turkey

	2003	2005	2010	2015	2020
Primary energy supply (ktoe)					
Hydro	3038	4067	4903	7060	9419
Geothermal, solar and wind	1215	1683	2896	4242	6397
Biomass and waste	5748	5325	4416	4001	3925
Renewable energy production	10,002	11,074	12,215	15,303	19,741
Share of total domestic production (%)	42	48	33	29	30
Share of TPES (%)	12	12	10	9	9
Generation (GWh)					
Hydro	35,330	47,287	57,009	82,095	109,524
Geothermal, solar and wind	150	490	5274	7020	8766
Renewable energy production	35,480	47,777	62,283	89,115	118,290
Share of total generation (%)	25	29	26	25	25
Total final consumption (ktoe)					
Geothermal, solar and wind	1134	1385	2145	3341	5346
Biomass and waste	5748	5325	4416	4001	3925
Renewable energy TFC	6882	6710	6561	7342	9271
Share of TFC (%)	11	9	7	6	6

Source: Ref. [10].

It is apparent that, in 2004, wind energy was in the leading position between renewables except for hydropower with regard to installed capacity (18.9 MW), followed by geothermal (15 MW). However, combustible renewable and waste was the leading electricity producer with 0.22% of the total electricity production of the three, followed by wind energy with 0.20% of the production. The relatively high share in the electricity produced reflects the reliability of geothermal plants, which can be operated at capacity factors in excess of 90%. Geothermal energy is independent of weather, as opposed to solar, wind, or hydro applications. It has an inherent storage capability and can be used both for base load and peak power plants. However, in most cases, it is more economical to run the geothermal plants as base load suppliers [22].

TEAS states that its average net generating costs are as indicated in Table 10. Geothermal energy in Turkey is 77.7%, 21.6%, 27.7%, 9.8%, and 56.9% cheaper than hard coal, lignite, fuel-oil, wind, and natural gas, respectively.

A cost comparison between geothermal energy and other energy production methods is shown in Table 11. From this, it can be seen that the current energy cost between renewable energy sources is lowest for geothermal energy, followed by wind, biomass, solar thermal, and hydraulic, respectively.

Despite that about two-thirds of renewable energy is used in Turkey for heat; there are no specific targets and policies in place to promote heat production from renewables. While at present non-commercial biomass dominates the use of renewables for heat production, there is also a large potential for the use of geothermal and solar thermal applications in Turkey. The use of geothermal and solar thermal energy of Turkey is planned to double between 2003 and 2010. The Geothermal Energy Law is planned to have provisions, which could provide a significant boost for the use of this resource for

Table 9
Status of electricity production from renewables

	Electricity production													
	1960		1970		1980		1990		2000		2003		2004	
	GWh	%	GWh	%	GWh	%	GWh	%	GWh	%	GWh	%	GWh	%
Hydropower	1002	96.1	3033	94.8	11,348	98.8	23,148	99.7	30,879	98.9	35,330	99.3	46,084	99.4
Wind	—	—	—	—	—	—	—	—	33.4	0.1	61.4	0.2	57.7	0.13
Geothermal	—	—	—	—	—	—	80.1	0.3	75.5	0.2	88.6	0.2	93.2	0.20
Combustible renewables and waste	40.5	3.9	165.7	5.2	135.7	1.2	—	—	220.2	0.7	115.9	0.3	104	0.22
Total	1042.5	100.0	3198.7	100.0	11,483.7	100.0	23,228.1	100.0	31,208.1	100.0	35,596	100.0	46,339	100.0

	Installed capacity										
	1960 MW	1970 MW	1980 MW	1990 MW	%	2000 MW	%	2003 MW	%	2004 MW	%
Hydropower	411.9	725.4	2130.8	6764.3	99.7	11,175.2	99.7	12,578.7	99.7	12,645.4	99.7
Wind	—	—	—	—	—	18.9	0.2	18.9	0.1	18.9	0.1
Geothermal	—	—	—	17.5	0.3	17.5	0.2	15	0.1	15	0.1
Combustible renewables and waste	—	—	—	—	—	—	—	—	—	—	—
Total	411.9	725.4	2130.8	6781.8	100.0	11,211.6	100.0	12,612.6	100.0	12,679.3	100.0

Source: Ref. [13].

Table 10
Net power generating cost by energy input, TEAS and DSI

Fuel input	Cost (US cents/KWh)
Hard coal	4.37
Lignite	2.99
Fuel oil	3.14
Diesel	16.24
Geothermal	2.46
Wind	2.7–3.1
Natural gas	3.86
Average thermal (TEAS)	3.56
Dam	0.14
Lake	1.11
Run-of-river	0.68
Average hydro (DSI)	0.16
Average TEAS + DSI	1.96

Source: Refs. [23,10].

Table 11
Production cost of 1 kWh energy (cent)

Power source	Minimum	Maximum	Average
Solar thermal hybrid	6.0	7.8	6.9
Hydraulic	5.2	18.9	12.1
Wind	4.7	7.2	6.0
Biomass	4.2	7.9	6.1
Geothermal	4.3	6.8	5.6
Nuclear	5.3	9.3	7.3
Natural gas	4.4	5.0	4.7
Coal	4.5	7.0	5.8

Source: Ref. [24].

residential heating [10]. Table 8 shows the status of direct heat production from renewables. As can be seen from table, while biomass and waste meet at least 83.5% of the total final consumption in 2003, geothermal, wind, and solar have supplied 16.5%.

6. Conclusion

Geothermal energy in Turkey is clean and cheaper than the other fossil and renewable energy sources and therefore is a promising alternative. The main conclusions that can be drawn from the present study on geothermal energy and other energy sources in Turkey are listed below:

- Mostly, the biomass energy and hydraulic energy among renewable resources are used to meet a part of the energy need in Turkey. Although geothermal energy comes after them, its usage is limited. In comparison to fossil fuels, geothermal energy has more advantages such as being renewable, reliable, clean, and a cheap domestic energy

resource. Therefore the development studies and investments in this sector should be supported.

- The present use of geothermal energy is a very small fraction of the identified geothermal potential. Four per cent of geothermal source potential of Turkey is only evaluated up to 2005. When Turkey uses all of the total geothermal potential it can meet 12.7% of the total energy need (heat + electricity) from geothermal energy.
- The total electricity production from renewables in 2004 was 46,339 GWh. By far the largest contribution (99.4%) came from hydropower, but 0.2% came from combustible renewable and waste, 0.2% from geothermal, and 0.1% from wind.
- Geothermal energy in Turkey is 77.7%, 21.6%, 27.7%, 9.8%, and 56.9% cheaper than hard coal, lignite, fuel-oil, wind, and natural gas, respectively. The current energy cost between renewable energy sources is lowest for geothermal energy, followed by wind, biomass, solar thermal, and hydraulic, respectively.
- Taking into consideration the future energy need in Turkey, it is clear that geothermal energy has an important role in meeting it, but it is not sufficient by itself.

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